Chemical Process Instrumentation

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Lecture – 40
Temperature Measurement
(Contd.)

Welcome to lecture 40 of week 8. So, this is the last lecture on temperature measurement. As of now, we have talked about various temperature measuring instruments such as thermal expansion methods thermoelectric methods as well as electrical resistance. Now, we will talk about temperature measuring instruments that are based on radiation principles.

As of now the temperature measuring instruments that you have talked about it was necessary for the instrument to bring it in contact with the medium of temperature you wanted to measure. So, now, we will talk about temperature instruments which are of non contacting type meaning you do not have to bring the temperature measuring instrument in direct contact with the object whose temperature you want to measure. So, these instruments are based on principle of radiation.

So, in briefly review, the principle of thermal radiation and then we will talk about two temperature measuring instruments based on thermal radiation principles, there total radiation parameter and optical radiation parameter.

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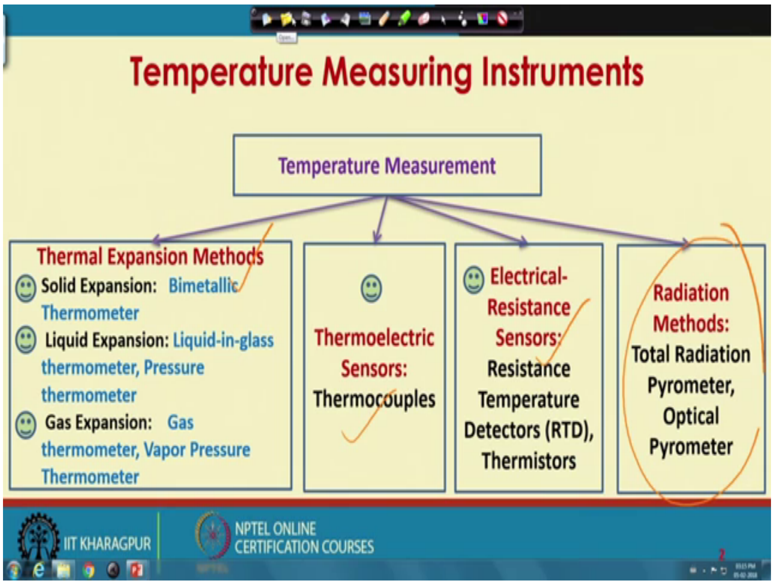

So, we have talked about thermal expansion methods thermoelectric sensors, it take resistance sensors, you take electrical resistance sensors. Today, we will talk about radiation methods under which we will talk about total radiation parameters and optical parameter.

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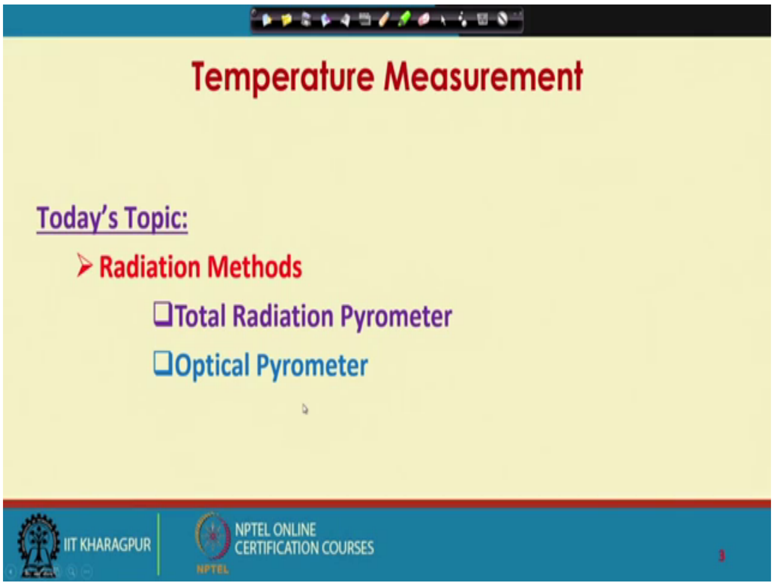

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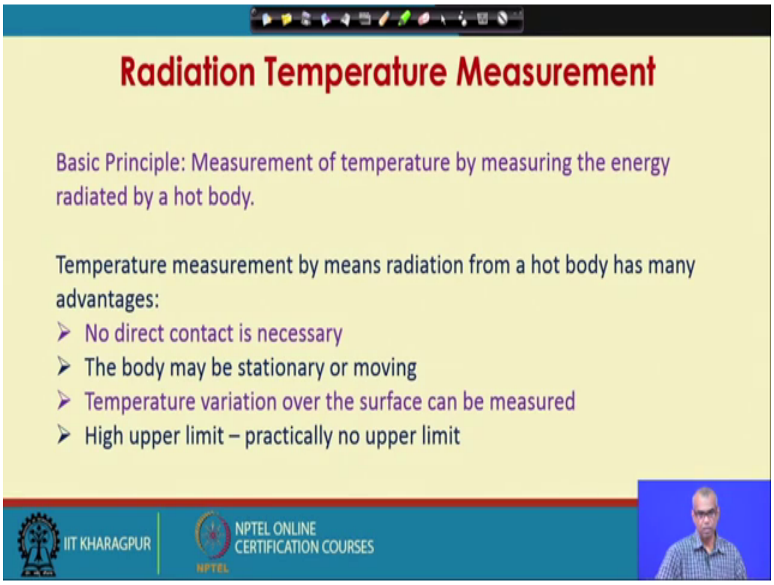

So, this is our today's topic. So, as I just mentioned the basic principle on which radiation temperature measurement depends as follows we measure the temperature by measuring the energy radiated by a hot body each body which is above absolute zero temperature will radiate thermal radiation and the intensity of the radiation is linked to the temperature of the body. So, it is possible to measure temperature by measuring the energy radiated by hot body.

Temperature measurement by means of radiation from a hot body has several advantages such as no direct contact is necessary the body may be stationary or moving temperature variation over the surface can be measured high upper limit. In fact, practically there is no upper limit, please note that it is also possible to measure temperature of a moving object using radiation temperature measurement.

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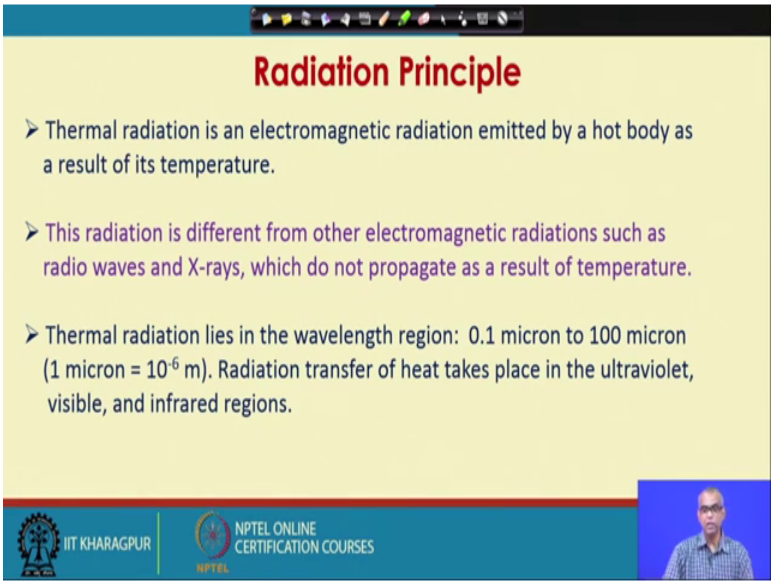

Let us briefly review radiation principles thermal radiation is an electromagnetic radiation emitted by hot body as a result of its temperature this radiation is different from other electromagnetic radiation such as radio waves and X-rays which do not propagate as a result of temperature.

Thermal radiation lies in the wavelength region of point one micron to hundred micron one micron is 10 to the power minus 6 meter radiation transfer of heat takes place in the ultraviolet visible and infrared regions.

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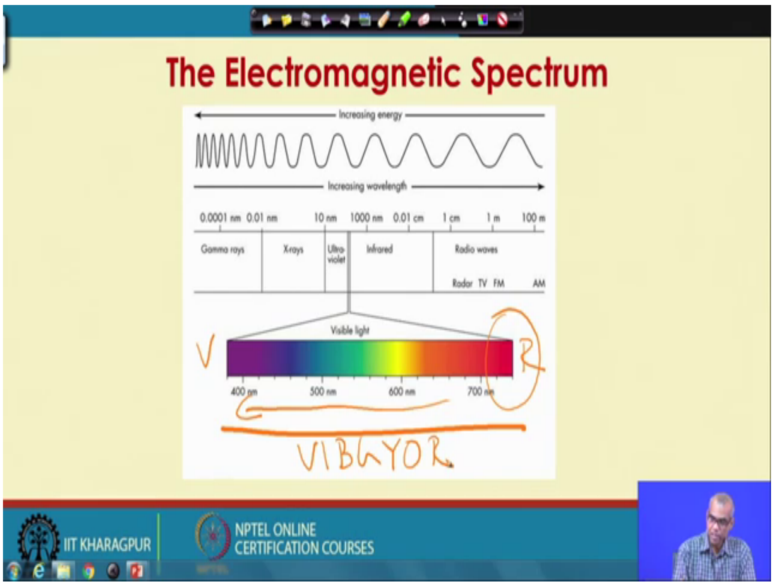

So, this shows the electromagnetic spectrum. So, wavelength increases as we go in this direction so; obviously, energy increases as we go in this direction this is the visible region which is roughly 0.38 micrometer to 0.78 micrometer. So, let us say 380 nanometer to 780 nanometer.

The thermal radiation happens in this visible region as well as part of UV and infrared regions. So, this is the region over which the thermal radiation takes place UV visible region and infrared region also look at here how the color changes with change in wavelength in the visible region the wavelength which are higher or longer has red color and as the wavelength decreases; that means, you go towards shorter wavelength as you go towards shorter wavelengths the color changes from red to yellow to violet. So, this is violet this is red and you may be familiar with v i b g y o r. So, so wavelength decreases and wavelength increases as you go from violet to red and as you go from red to violet wavelength decreases.

So, longer wavelength in the visible region will give you color red and in the shorter wavelength it will give you violet color we will make use of this information later also note that if a body emits radiations of all wavelength in the visible region, it will appear white.

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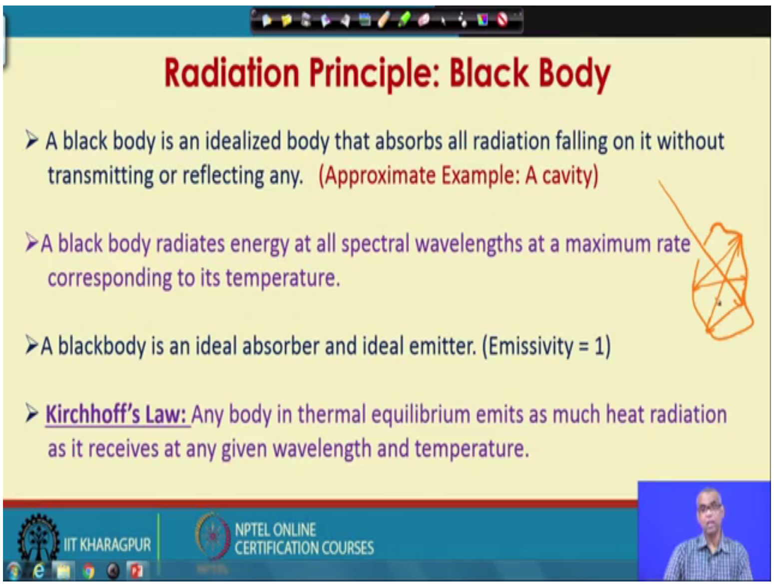

Now, what is a black body? A black body is an idealized body that absorbs all radiation falling on it without transmitting or reflecting any an approximate example is a cavity if you have a whole in a body and radiation enters through this cavity and then it can get reflected several times on the walls and finally, gets fully absorbed. So, a cavity is an approximate example or idealization of a black body; a black body radiation energy at all spectral wavelengths at a maximum rate corresponding to its temperature.

So, a black body is an ideal observer and ideal emitter its emissivity is equal to 1 which is the maximum possible value Kirchhoff's law says anybody in thermal equilibrium emits as much heat radiation as it receives at any given wavelength and temperature.

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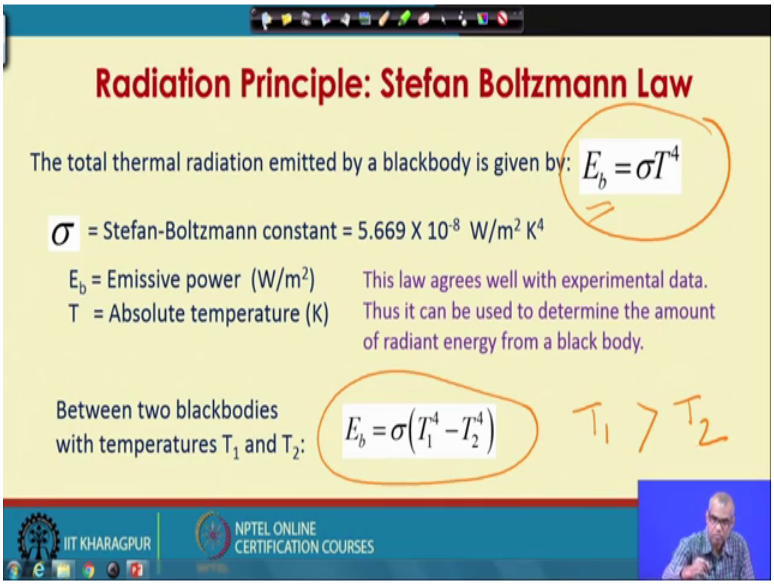

Now, we will talk about two different laws first one is Stefan Boltzmann and then you will talk about Planck's law the total thermal radiation emitted by black body is given is Stefan Boltzmann law the total thermal radiation emitted by black body is represented as E b equal to sigma K to the power 4 where sigma is Stefan Boltzmann constant and has a value of 5.669 into 10 to the power minus eight volt per meter square Kelvin to the power four.

E b is the emissive power expressed as volt per watt per meter square T is absolute temperature expressed in Kelvin. This law agrees well with experimental data thus it can be used to determine the amount of radiant energy from a black body between two black bodies with temperature T 1 and T 2, we can extend this equation as E b equal to sigma into T 1 to the power 4 minus T 2 to the power 4 where temperature T 1 is greater than temperature T 2.

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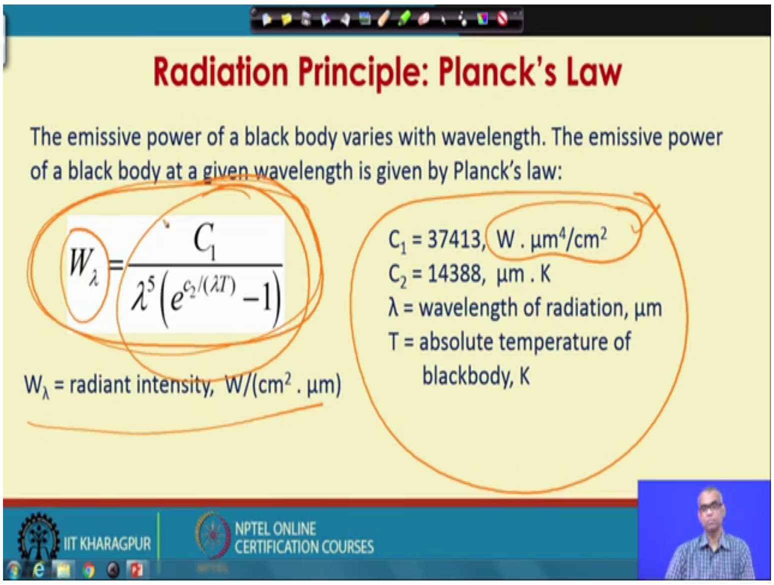

Now, let us talk about Planck's law the emissive power of a black body varies weak wavelength the emissive power of a black body at a given wavelength is given by Planck's law and this is expressed as this expression radial insane intensity W lambda is equal to C 1 by lambda to the power 5 into E to the power C 2 minus lambda T minus one here there are 2 constants C 1 and C 2 the value of C 1 is 37413 what micrometer to the power 4 per centimeter square C 2 is 14388 micrometer Kelvin.

Lambda wavelength of radiation expressed in micrometer and T is absolute temperature of black body expressed in Kelvin radiant intensity is expressed as what per centimeter square into micrometer. So, please take care of the units if you express in different units instead of using micrometer and centimeter the values of C 1 and C 2 will accordingly change.

So, please note that this equation relates the radiant intensity with temperature. So, this equation for a given wavelength tells you the amount of radiant intensity at a particular temperature.

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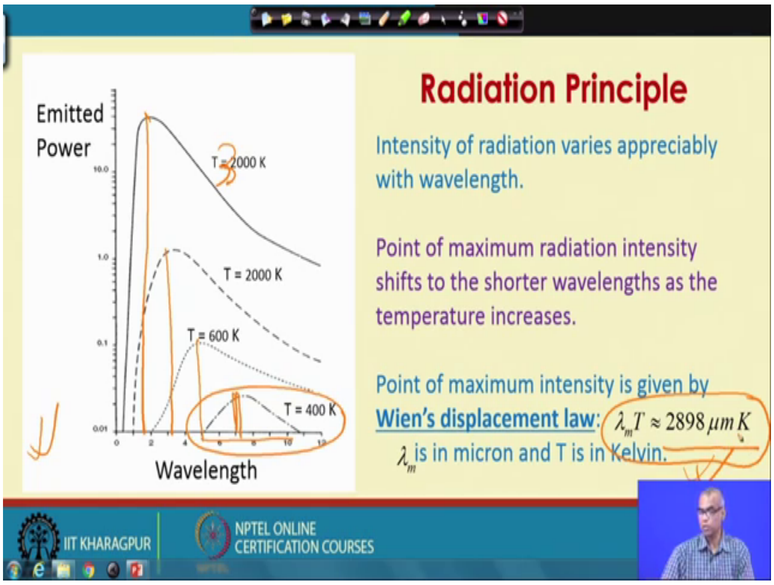

Now, if I plot this emitted power versus wavelength at various temperatures, we get a plot which is shown on the screen intensity of radiation varies appreciably with wavelength point of maximum radiation intensity shifts to the shorter wavelength, as the temperature increases note that if you focus your attention on a particular temperature. Let us say 400 Kelvin the emitted power varies appreciably with change in wavelength number 1.

Number 2 there is a wavelength at which the emitted power is maximum. So, this is the wavelength at which emitted power is maximum for 400 degree Kelvin and this is the wavelength for which the emitted power is maximum at 600 degree Kelvin note; that as the temperature increase the wavelength at which maximum radiation intensity occurs shifts to the shorter wavelength can see it from the temperature at 2000 degree Kelvin as well as temperature higher than 2000 degree Kelvin. So, this may be say 3000 degree Kelvin

So, this the maximum happens at the shortest wavelength for the highest temperature the point of maximum intensity is given by Wiens displacement law which states that the product of the wavelength at which the maximum intensity happens multiplied by the temperature corresponding temperature in absolute scale is a constant and that constant is 2898 micrometer Kelvin.

So, here I express the wavelength in micrometer and micron and the temperature absolute temperature is in Kelvin. So, the product of lambda max which is the wavelength at which maximum intensity occurs multiplied by the temperature is constant and that constant is 2898 micrometer Kelvin.

So, this equation tells you that as temperature increases the lambda max decreases because the product will be constant. So, if I start hitting an object initially the temperature will be lower. So, the maximum intensity of the radiation will happen at a wavelength which is the longer region.

So, if it is in the visible region it may be around red because the red has maximum wavelength in the visible region as the temperature increases the lambda max will decrease, it will shift to the shorter wavelength and the color will go towards violet. So, maybe red to yellow to violet like that when it is very high temperature is very high the body will emit radiation of all wavelength in the visible region.

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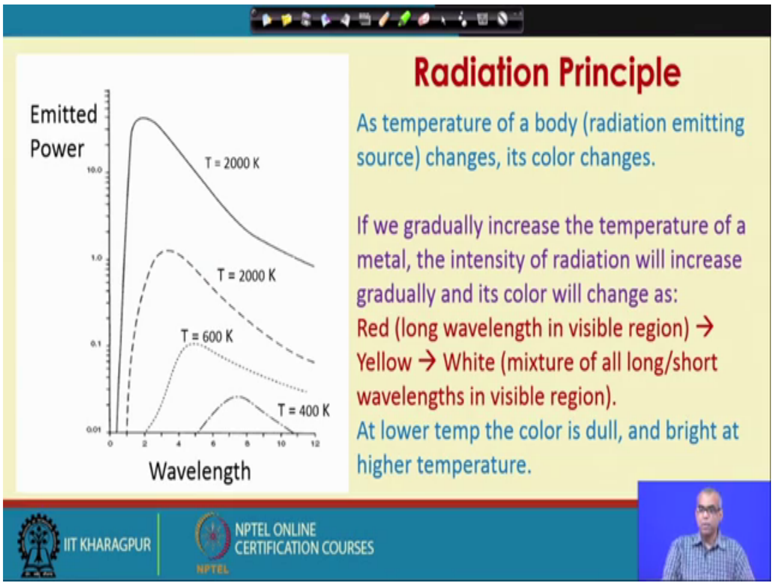

So, it will appear white. So, as temperature of a body changes its color changes if you gradually increase the temperature of a metal the intensity of radiation will increase gradually and its color will change as red, yellow to white, red is red corresponds to longer wavelength in the visible region and white corresponds to mixture of all wavelengths long short wavelengths in the visible region.

So, as you go on hitting the shorter at shorter wavelength maximum intensity happens at lower temperature the color is dull and bright at higher temperature. So, at lower temperature color is dull because of longer wavelength and at high temperature the color is bright because of shorter wavelength.

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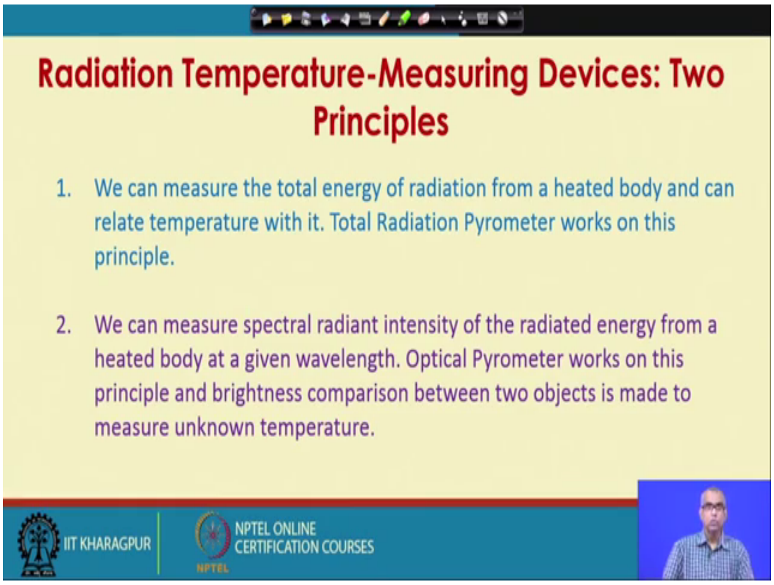

So, there are two principles on which radiation temperature measuring devices are designed one we can measure the total energy of radiation from heated body and can relate temperature with it total radiation pyrometer works on this principle

Principle number two we can measure spectral radiant intensity of the radiated energy from a heated body at a given wavelength optical pyrometer works on this principle and brightness comparison between two objects is made to measure unknown temperature. So, in optical pyrometer will compare brightness of two objects one object is a reference object whose temperature will be known.

So, if the brightness of the objects whose temperature is unknown matches well with the brightness of the object whose temperature is known, I can find out the temperature for the object temperature whose temperature is not known.

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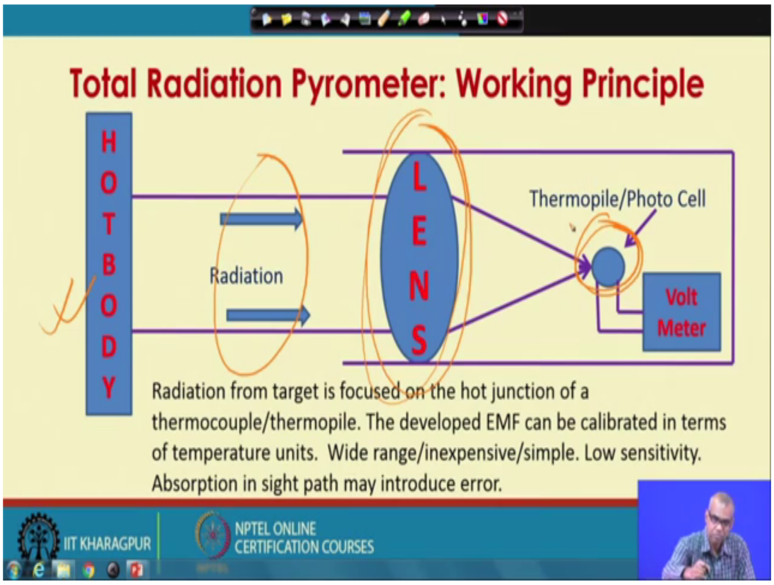

So, this is a schematic of total radiation pyrometer radiation from target is focused on the hot junction of a thermocouple or thermo coil the developed EMF can be calibrated in terms of temperature units wide range it has wide range this is inexpensive and this is simple; however, it is low sensitivity absorption in the of site path may introduced some error.

So, you use the lanes to focus the radiation from the hot of hot body the temperature of the hot body I want to find out. So, the radiation is being focused by these lines on to the thermocouple or a thermo coil or a photocell is basically a temperature measuring device you know what happens or how are thermocouple measures temperature

So, when the radiation from the hot body is focus on to the thermo coil or a thermocouple and EMF will be produced corresponding to the temperature. So, this EMF can be calibrated in terms of temperature units as you notice that this is a very simple device it is inexpensive also, it has wide range; however, it has low sensitivity and absorption of radiation in side path may introduce error in the measurement.

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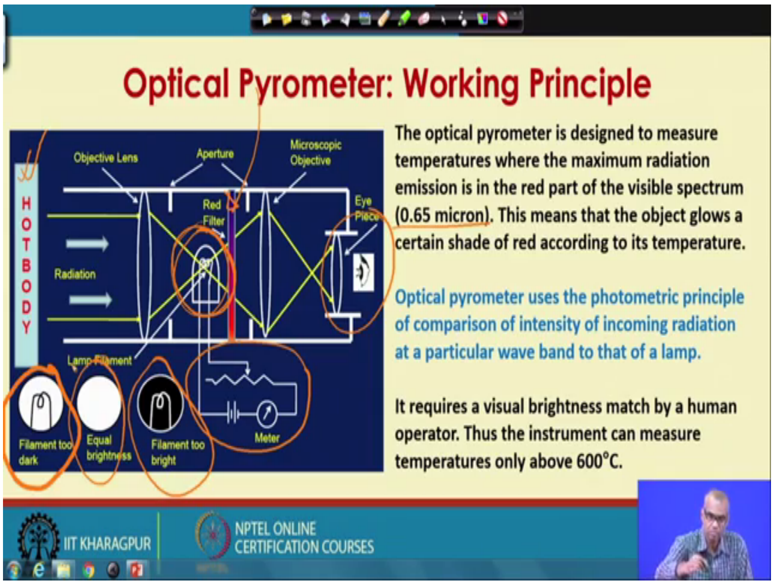

Next, we will talk about optical pyrometer the optical pyrometer is designed to measure temperatures where the maximum radiation emission is in the rate part of the visible spectrum that is 0.65 microns. This means that the object glows a certain shade of rate according to its temperature; optical pyrometer uses the photometric principle of comparison of intensity of incoming radiation at a particular waveband to that of a lamp. It requires a visual brightness match by a human operator does the instrument can measure temperature only above 600 degree Celsius.

So, the way optical pyrometer work is as follows we have the hot body whose temperature we want to measure this is a filament which can be heated to a particular temperature by sending different amount of current to the filament now the radiation from the hot body is focused on the filament.

So, the image of the hot body is superimposed on this filament and then I can see this filament through an eye piece. So, what we do first is we send a particular amount of current to this filament depending on that the filament will assume some temperature corresponding to this temperature the brightness of the filament will be defined.

Now, I view the filament through this eye piece and through a red filter this red filter improves the accuracy in the measurement because channel the red filter will pass a narrow wavelength light through this red filter which corresponds to 0.65 micrometer. Now, when you view the filament to the eye piece three things can happen first the filament may be too dark compared to the hot body; that means, the brightness of the hot body may be much higher than the brightness of the filament. In that case you will see a dark filament on a white background, in case if the filament is too bright compared to hot body. In other words the brightness of the filament is higher than the brightness of the hot body you will see a white filament on a dark background.

But if the brightness of the filament and the brightness of the hot body matches well then the filament will disappear and we will see all white. So, the point of measurement is as follows you manipulate or you change the current that is being sent through the filament; that means, you are heating up the filament at different temperatures until the brightness of the filament matches with the brightness of the hot body under circumstance, you know that the temperature of the filament is a measure of the temperature of the hot body and the temperature of the hot body can be measured in terms of or calibrated in terms of current that you are flowing to the filament .

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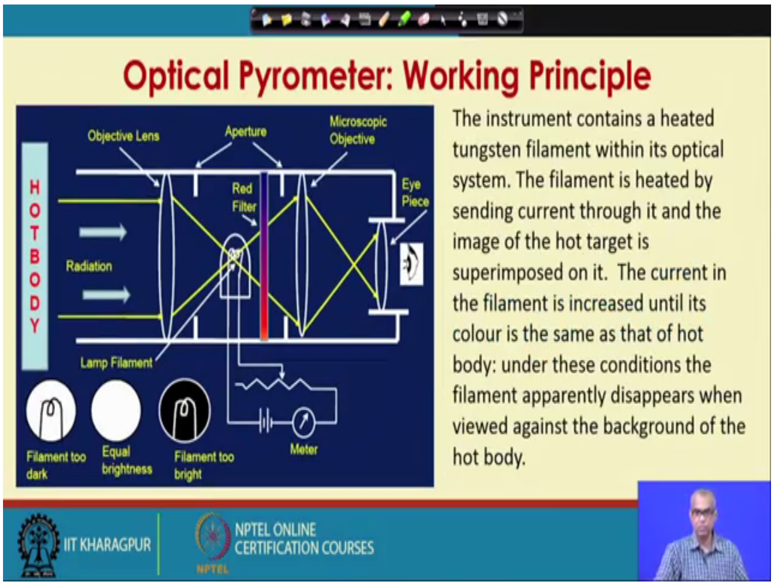

So, the instrument contains a heated tungsten filament within its optical system, the filament is heated by sending current through it at the image of the hot target is superimposed on it by this objective lens. The current in the filament is increased until it is color is the same as that of the hot body under these conditions the filament, apparently, disappears when viewed against the background of the hot body.

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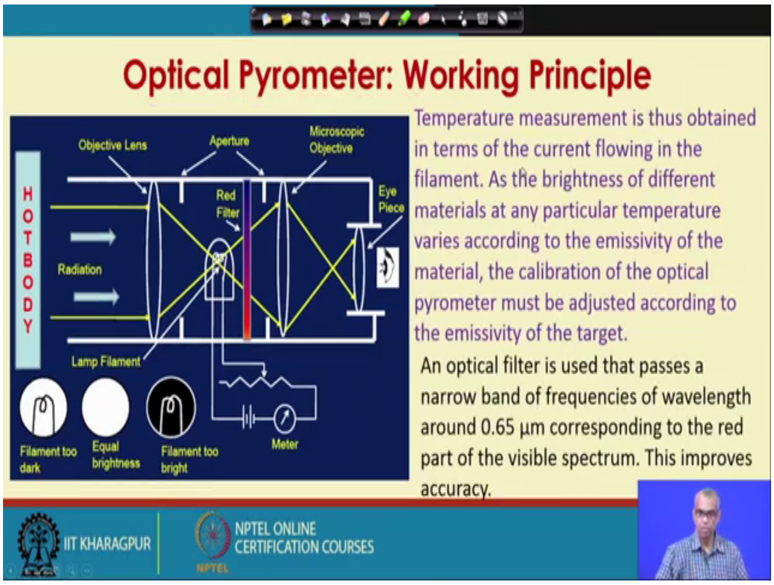

Temperature measurement is thus obtained in terms of the current flowing in the filament as the brightness of different materials at any particular temperature varies according to the emissivity of the material. The calibration of the optical pyrometer must be adjusted according to the emissivity of the target, an optical filter is used that passes and narrowband of frequencies of wavelength around 0.65 micrometer corresponding to the red part of the visible spectrum this improves accuracy.

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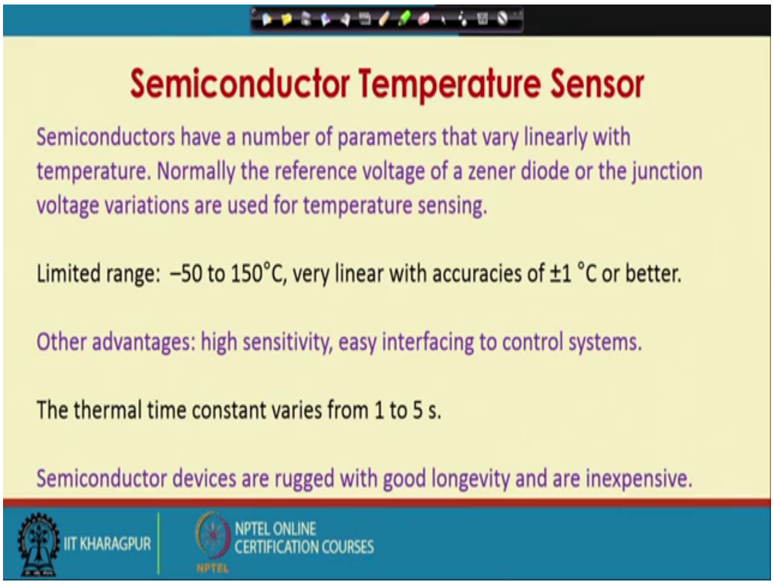

Next week we quickly talk about semiconductor temperature sensor semiconductors have a number of parameters that vary linearly with temperature normally the reference voltage of a Zener diode or the junction voltage variations are used for temperature sensing semiconductor temperature sensors have limited range minus 50 to 150 degree Celsius; however, they are very linear with accuracies of plus minus 1 degrees Celsius or better.

There are several other advantages such as high sensitivity easy interfacing to control systems the thermal time constant where is from 1 to 5 seconds semiconductor devices are ragged with good longevity and are inexpensive.

Now, we have talked about various temperature measuring instrument, but how do you select a temperature sensor for your application while selecting a temperature sensor.

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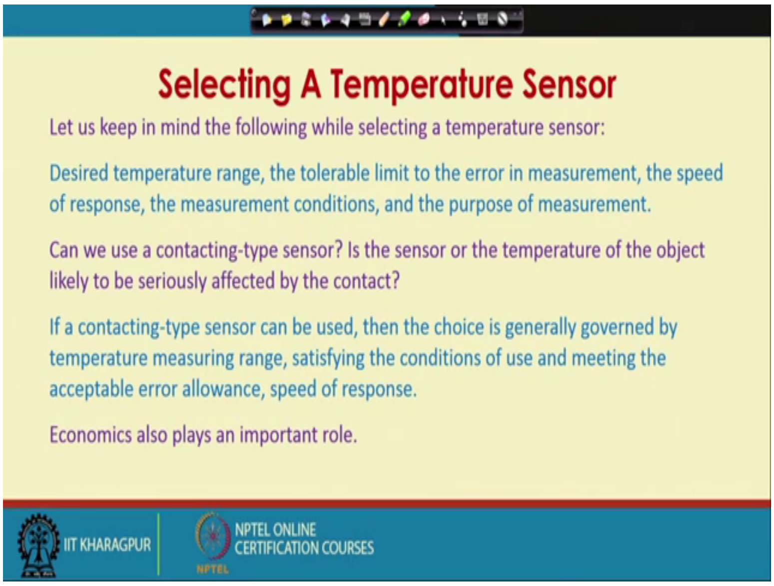

Let us keep in mind the following desired temperature range the tolerable limit to the error in measurement, the speed of response the measurement condition and the purpose of measurement.

Let us ask how can you use a contacting type in sensor is the sensor or the temperature of the object likely to be seriously affected by the contact under such circumstances have to use a protective case for the sensor. If a contacting type sensor can be used then the choice is generally governed by temperature measuring range satisfying the conditions of use and meeting the acceptable error allowance speed of response of course, economics also plays an important role in choice of suitable temperature sensor.

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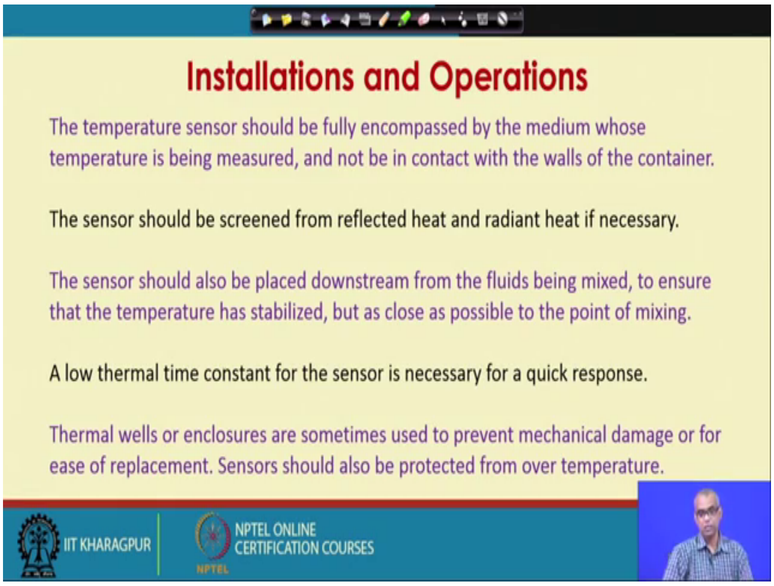

Finally, we briefly talked about installations operations and care of temperature sensors the temperature sensors should be fully encompassed by the medium whose temperature is being measured and not be in contact with the walls of the container.

The sensors should be screened from reflected heat and radiant heat if necessary the sensors should also be replaced downstream from the fluids being mixed to ensure that the temperature has stabilized. But as close as possible to the point of mixing a low thermal time, constant for the sensor is necessary for quick response thermal oils or enclosures are sometimes used to prevent mechanical damage or for ease of replacement sensors should also be protected from over temperature.

Now, we stop our discussion on temperature measurement.